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Induced sheath voltages in 110 kV power cables – case study*

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Abstract: This paper considers electric shock hazard due to induced sheath voltages in 110 kV power cables. The purpose of this paper is to find an optimal configuration of the power cable system, taking into account electric shock hazard and ability of the system to transfer maximal power. A computer simulations on a computer model of the local power system, comprising high voltage power cables, were carried out. This model enables to analyse various configurations of the metallic cable sheaths bonding and earthing (single-point bonding, both-ends bonding, cross-bonding) and their impact on induced voltages in the cable sheaths. The analysis presented in the paper shows, that it is possible to find an optimal configuration of the complicated power cable system, in terms of electric shock hazard, maximal power transfer as well as economic aspects.

Key words: electric shock hazard, induced voltages, power cables, power system

1. Introduction

The induced voltages in the concentric metallic sheaths of high voltage power cables are discussed in [1-6]. The value of these voltages mainly depends on a length, construction and configuration of the cables. In general, the induced voltages in cable sheaths may be calculated according to the following expressions:

$$\underline{U}_{\mathrm{As}} = j\omega \cdot \underline{I} \cdot 2 \cdot 10^{-7}\left(-\frac{1}{2}\ln\frac{2m_{\mathrm{AB}}^2}{d \cdot m_{\mathrm{CA}}} + j\frac{\sqrt{3}}{2}\ln\frac{2m_{\mathrm{CA}}}{d}\right), \tag{1}$$

$$\underline{U}_{\mathrm{Bs}} = j\omega \cdot \underline{I} \cdot 2 \cdot 10^{-7}\left(+\frac{1}{2}\ln\frac{4m_{\mathrm{AB}} \cdot m_{\mathrm{BC}}}{d^2} + j\frac{\sqrt{3}}{2}\ln\frac{2m_{\mathrm{BC}}}{m_{\mathrm{AB}}}\right), \tag{2}$$

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$$\underline{U}_{\mathrm{Cs}} = j\omega \cdot \underline{I} \cdot 2 \cdot 10^{-7}\left(-\frac{1}{2}\ln\frac{2m_{\mathrm{BC}}^2}{d \cdot m_{\mathrm{CA}}} - j\frac{\sqrt{3}}{2}\ln\frac{2m_{\mathrm{CA}}}{d}\right), \tag{3}$$

where: U_{As}, U_{Bs}, U_{Cs}, – induced voltages in sheath of the cable in phase A, B and C respectively, I – load current in the cable conductor, d – geometric mean sheath diameter, m_{AB}, m_{BC}, m_{AC} – axial spacing of phases A and B, B and C, A and C respectively.

In practice, sheaths of high voltage cables can operate with:

- single-point bonding,
- both-ends bonding,
- cross-bonding.

Single point bonding is the simplest configuration of sheaths but can be dangerous for persons because of the highest value of induced voltages at the unearthed end. Special measures must be applied in substations for persons safety then. Both-ends bonding eliminates electric shock hazard due to induced voltages but this arrangement is rather not acceptable, because current-carrying capacity of the cables significantly decreases (due to power loss in the sheaths [7-9]) – in some cases over 50%. Cross-bonding reduces induced voltages at the unearthed end but it complicates structure of the power lines.

In this paper induced sheath voltages (in steady-state condition) in 110 kV underground power transmission system comprising three parallel cables per phase are considered. The cross-section of each conductor is equal to 2000 mm^2 and each concentric sheath is equal to 95 mm^2. Maximum ability of the system to power transfer is searched for. The total length of the power line is 1000 m. Figure 1 presents the overall structure of the analysed transmission system (assumed by an investor).

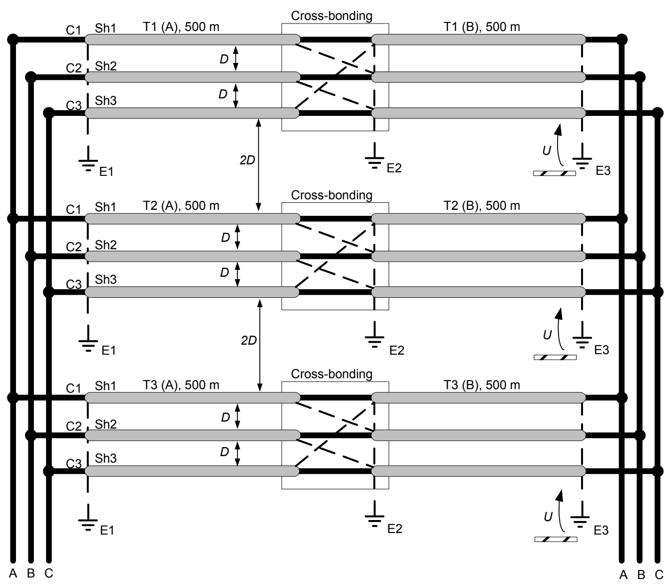


Fig. 1. Structure of the analysed transmission system; C1, C2, C3 – conductors in phase A, B and C respectively; Sh1, Sh2, Sh3 – sheaths in phase A, B and C; E1, E2, E3 – possible points of earthing, T1(A), T1(B), T2(A), T2(B), T3(A), T3(B) – sections of parallel cables, U – analysed sheath-to-earth voltage

The cables are in a flat formation. Distance between adjacent cables (C1-C2 and C2-C3) inside the section is equal to the outside diameter of the cable (*D* in Fig. 1). Distance to adjacent cables between sections is equal to twice of the outside diameter of the cable (2*D* in Fig. 1). The standard [10] defines permissible touch voltages U_{Tp} and permissible prospective touch voltages U_{vTp} (with additional resistances in earth path) as a function of time (Fig. 2).

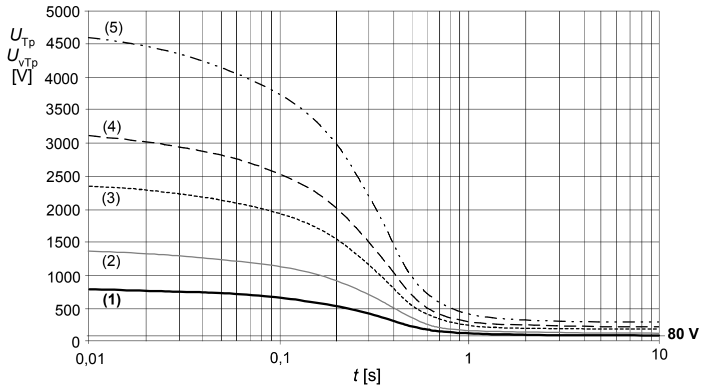


Fig. 2. Permissible touch voltage U_{Tp} (curve 1), and permissible prospective touch voltages U_{vTp} (with additional resistances – curves 2, 3, 4, 5) in high voltage substations [10]

For time exceeding 10 s – if no additional resistances in earth path – the permissible touch voltage U_{Tp} is equal to 80 V. This value is a representative value in the considered case. The cables and sheaths configuration is accepted when the induced voltages do not exceed 80 V.

The analysis was performed for the following configurations of the transmission system (for explanation of the symbols see Fig. 1):

- W1a: sheaths bonding and earthing in E1, cross-bonding in E2, cables configuration in sections T1, T2 and T3: C1-C2-C3, power transmission capacity 880 MW,
- W2a: sheaths bonding and earthing in E1, cables configuration in sections T1, T2 and T3: C1-C2-C3, power transmission capacity 880 MW,
- W2b: sheaths bonding and earthing in E2, cables configuration in sections T1, T2 and T3: C1-C2-C3, power transmission capacity 880 MW,
- W2c: sheaths bonding and earthing in E1 and E3, cables configuration in sections T1, T2 and T3: C1-C2-C3, power transmission capacity 420 MW,
- W3a: sheaths bonding and earthing in E1, cross-bonding in E2, cables configuration in sections T1, T3: C1-C2-C3, and T2: C3-C2-C1, power transmission capacity 880 MW,
- W4a: sheaths bonding and earthing in E1, cables configuration in sections T1, T3: C1-C2-C3, and T2: C3-C2-C1, power transmission capacity 880 MW,
- W4b: sheaths bonding and earthing in E2, cables configuration in sections T1, T3: C1-C2-C3, and T2: C3-C2-C1, power transmission capacity 880 MW,
- W4c: sheaths bonding and earthing in E1 and E3, cables configuration in sections T1, T3: C1-C2-C3, and T2: C3-C2-C1, power transmission capacity 420 MW.

2. Analysis of the induced voltages

The analysis of the induced voltages was performed with use of DIgSILENT PowerFactory® software. The sheath voltages and load currents in the cable conductors were calculated for the above mentioned configurations.

When configuration W1a is used (Fig. 3), induced voltage is relatively low in all cable sheaths. The permissible value of voltage (80 V) is exceeded, but slightly, in sheath Sh1 of the section T2 and sheath Sh3 of the section T3.

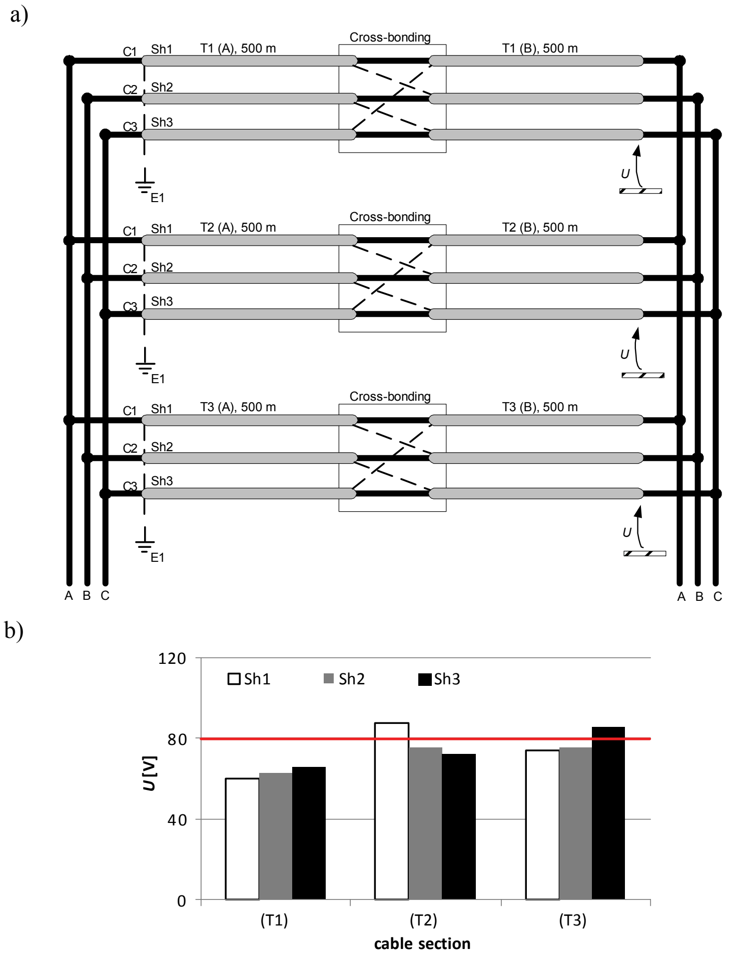


Fig. 3. Configuration W1a (a) and induced voltages in cable sheaths Sh1, Sh2, Sh3 of sections T1, T2, T3 (b); cables configuration in T1, T2, T3: C1-C2-C3; *U* – analysed sheath-to-earth voltage

For cables configuration in T2: C3-C2-C1 induced sheath voltages have risen (Fig. 4) in comparison to configuration in T2: C1-C2-C3 and in majority of cable sheaths these voltages significantly exceed 80 V.

Similarly to configuration W1a (in terms of values of induced voltages) is configuration W2b (Fig. 5). One can see that only in two cases (in sheath Sh1 of the section T1 and in sheath Sh3 of the section T3) induced sheath voltages exceed 80 V. This excess is slight. In other sheaths the voltage is less than 80 V.

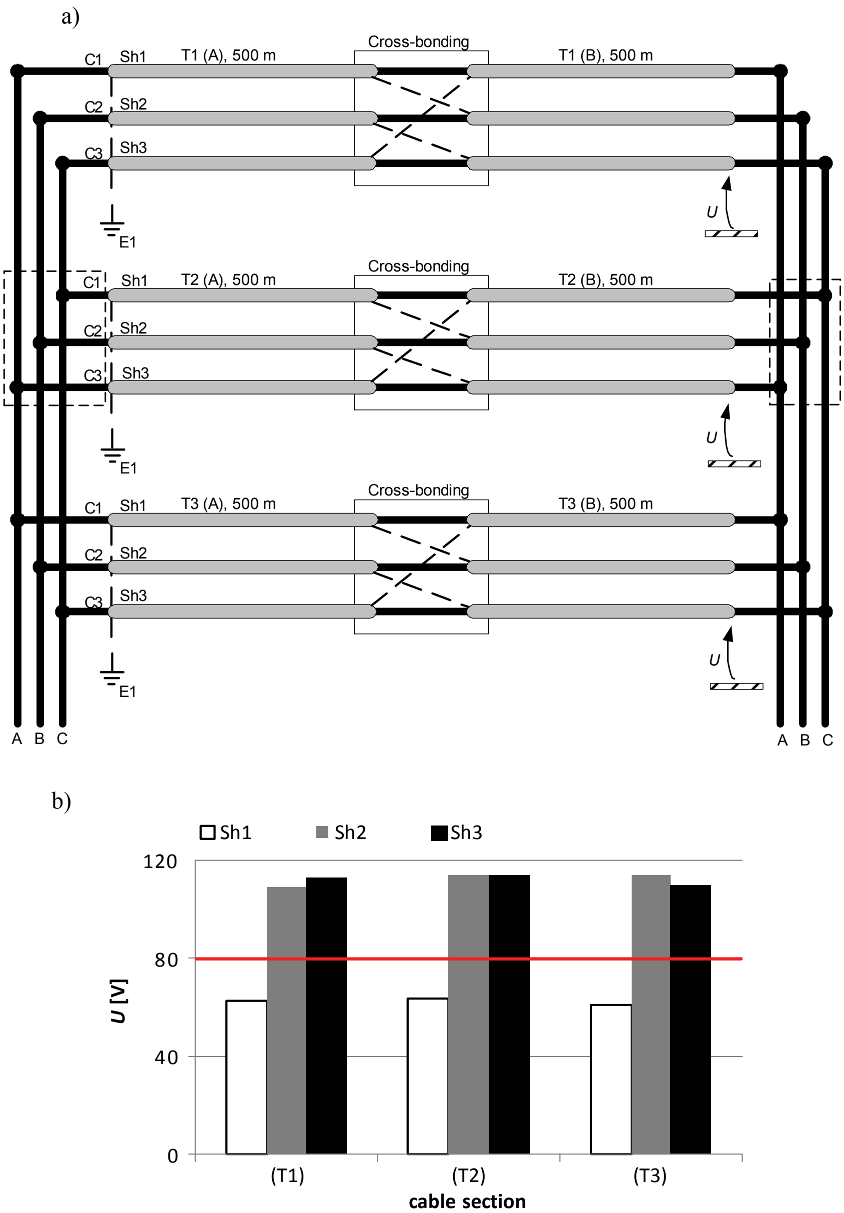
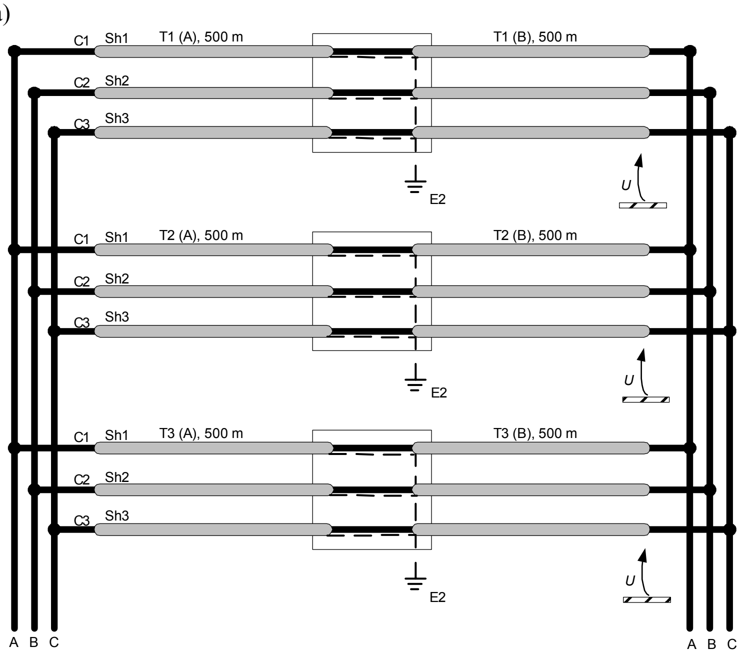


Fig. 4. Configuration W3a (a) and induced voltages in cable sheaths Sh1, Sh2, Sh3 of sections T1, T2, T3 (b); cables configuration in T1, T3: C1-C2-C3 and T2: C3-C2-C1; *U* – analysed sheath-to-earth voltage

a)



b)

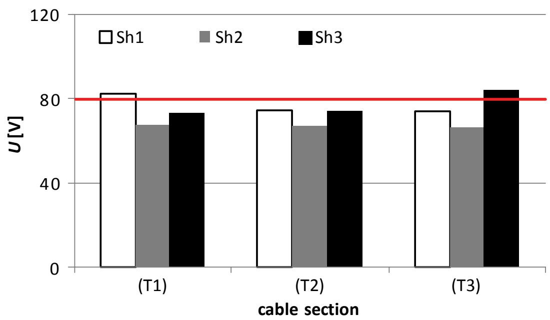
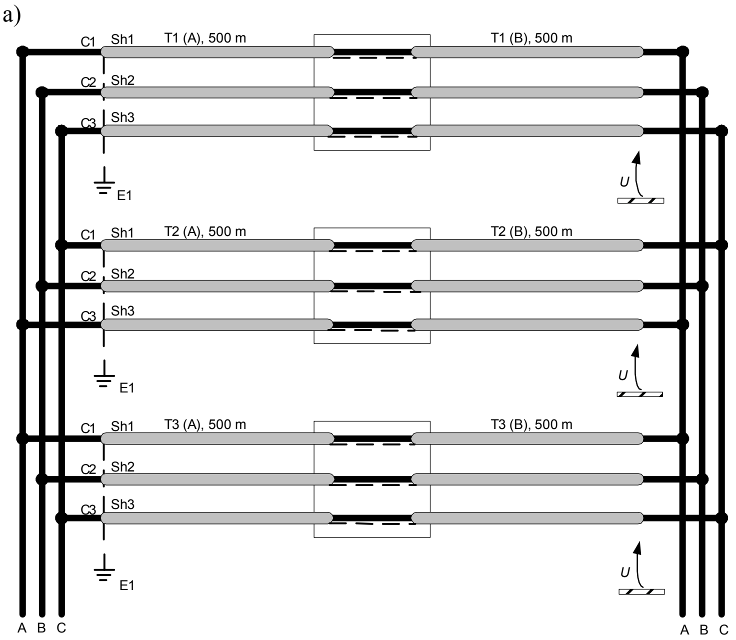


Fig. 5. Configuration W2b (a) and induced voltages in cable sheaths Sh1, Sh2, Sh3 of sections T1, T2, T3 (b); cables configuration in T1, T2, T3: C1-C2-C3; *U* – analysed sheath-to-earth voltage

The highest values of induced sheath voltage are for configuration W4a (Fig. 6). Single-point bonding in E1 and cables configuration in T2: C3-C2-C1 make that induced voltage, for power transfer 880 MW, is higher than 225 V for 6 from 9 sheaths. It is not acceptable value. Negligible values of induced voltages are achieved for both-ends bonding of cable sheaths (configurations of the transmission system W2c). However, this configuration can not also be accepted – for both-ends bonding the sheath circulating current appears (Fig. 7) and because of huge power losses the system is able to transmit only power not exceeding 420 MW (48% from 880 MW). The same values of induced voltages are for configuration W4c.

a)



b)

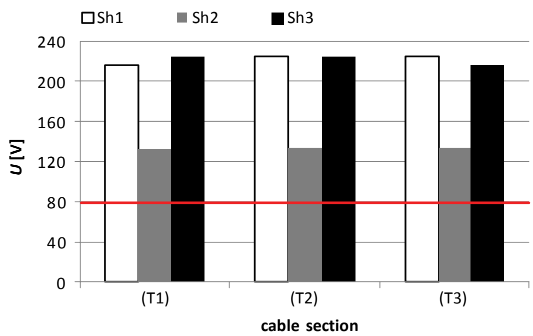


Fig. 6. Configuration W4a (a) and induced voltages in cable sheaths Sh1, Sh2, Sh3 of sections T1, T2, T3 (b); cables configuration in T1, T3: C1-C2-C3 and T2: C3-C2-C1; *U* – analysed sheath-to-earth voltage

The accumulative results of the induced sheath voltages and load currents calculations are presented in Figure 8. The voltage values are presented for full current-carrying capacity of the cables. For such a condition the maximum induced voltages are achieved.

Figure 9 presents limit of the power that can be transmitted while the induced voltages do not exceed 80 V. The optimal configuration i.e. allowing to transfer maximum power – while limiting induced sheath voltages to 80 V – is configuration W2b. The power transfer is equal to 830 MW (94% from 880 MW) in this case. The configuration W1a is acceptable as well. The system is able to transmit 800 MW (91% from 880 MW) then.

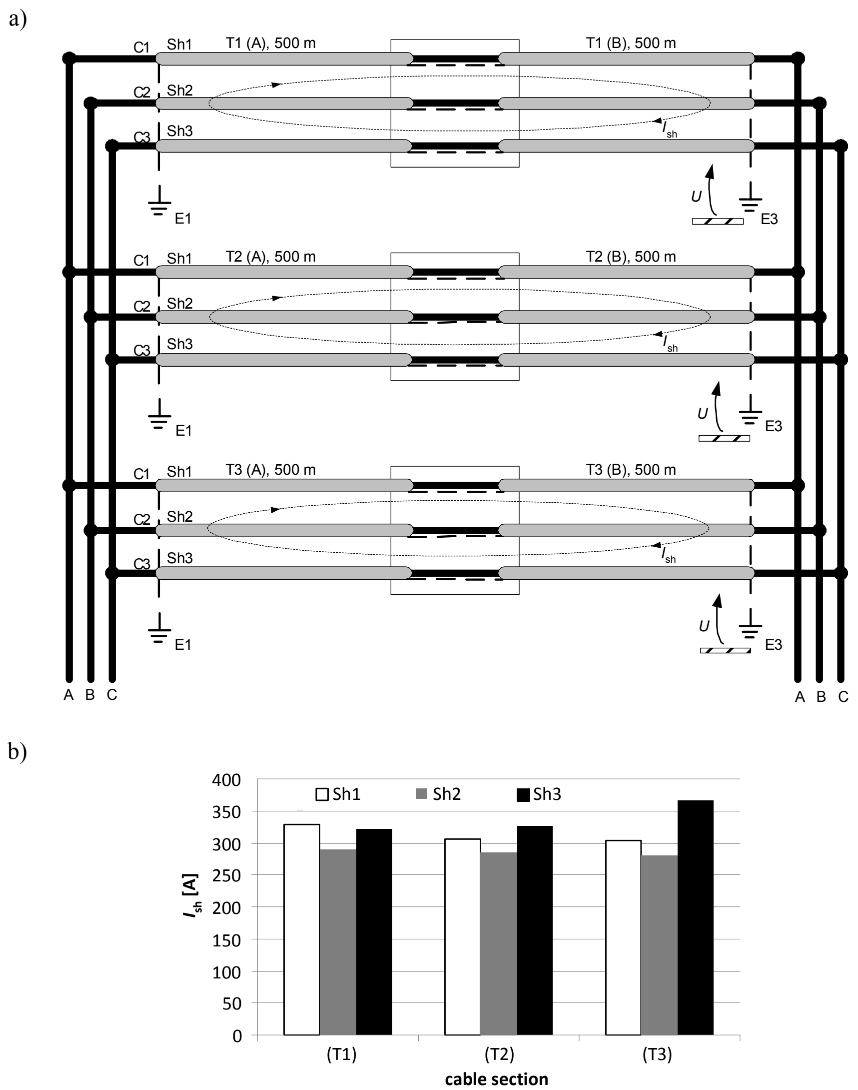


Fig. 7. Configuration W2c (a) and circulating currents I_{sh} in cable sheaths Sh1, Sh2, Sh3 of sections T1, T2, T3 (b); U – analysed sheath-to-earth voltage

3. Conclusions

Induced sheath voltages depend on way of bonding and location of earthing of the cable sheaths, and the cables transposition. For the analysed power transmission system, comprising three parallel cables per phase, earthing in point E2 (sheaths ends not connected to E1 and E3 – Fig. 5a) without cross-bonding is the optimal configuration. This configuration enables to transmit the highest level of power and the permissible touch voltage is not exceeded.

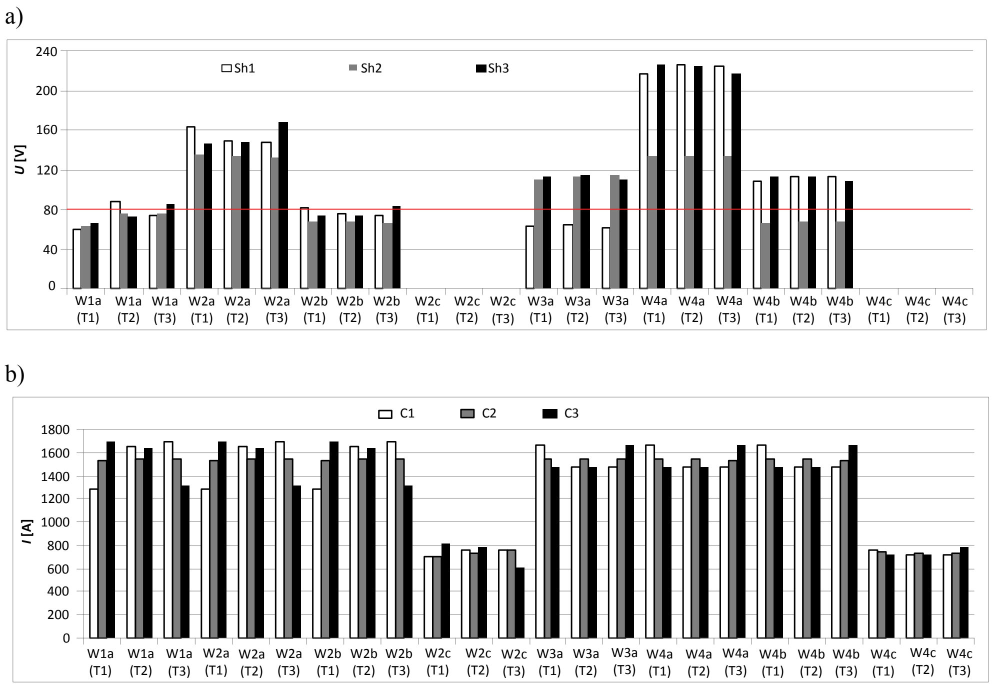


Fig. 8. Induced voltages in cable sheaths Sh1, Sh2, Sh3 (a) and load current in cable conductors C1, C2, C3 (b) for various configurations of the cables and sheaths – maximum power transmission (full current-carrying capacity of the cables is achieved)

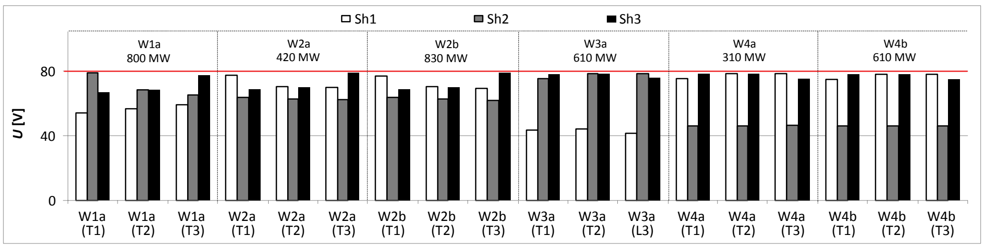


Fig. 9. Permissible power transmission and induced voltages in cable sheaths Sh1, Sh2, Sh3 for various configurations of the cables and sheaths – criterion: induced voltages should not exceed 80 V

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